IJSPT

CLINICAL COMMENTARY

A CONCEPTUAL MODEL FOR PHYSICAL THERAPISTS TREATING ATHLETES WITH PROTRACTED RECOVERY FOLLOWING A CONCUSSION

Mark Lundblad, DPT, MPH, OCS, CSCS[1]

ABSTRACT

Sports-related concussions are receiving growing attention in healthcare. Most concussions resolve spontaneously with little or no treatment, but twenty percent of concussions take longer than three weeks to resolve. In some cases, symptoms can last for five years following a traumatic brain injury. Physical Therapists have unique skills that can assist patients experiencing protracted recovery.

The purpose of this clinical commentary is to describe a new conceptual model that provides a framework for Physical Therapy management of patients with protracted recovery following a sports-related concussion. The end product is a visual diagram that represents the full scope of clinical practice that Physical Therapy can provide to an athlete following a concussion.

Level of Evidence: 5

Key Words: Conceptual Model, Post-Concussion Management, Sports

CORRESPONDING AUTHOR

Mark Lundblad
Cleveland Clinic Chagrin Falls Family Health Center
551 E. Washington St
Chagrin Falls, OH
Phone: (440) 893-9393
E-mail: mlundbla@ccf.org

[1] The Cleveland Clinic, Cleveland, OH, USA

INTRODUCTION

Background

A concussion is a mild traumatic brain injury caused by a direct or indirect biomechanical force to the brain.[1] This initial injury is followed by a secondary insult on the brain due to a metabolic cascade that places increased energy demands on the brain.[2,3] Each year 1.6 to 3.8 million sports-related concussions occur in the United States.[4] Eighty percent of concussions have been observed to recover within 7-10 days.[1] Twenty percent of the sports-related concussions take longer than three weeks to resolve.[5,6] Symptoms such as headaches (54%), dizziness (37%), and anxiety (63%) may persist for five years after a head injury, regardless of the severity of the injury.[7]

Predictors for having a protracted recovery include: loss of consciousness,[8] post-traumatic amnesia and retrograde amnesia,[8] and elevated symptom scores early after concussion.[8,9] Females have been shown to have increased risk of longer recovery compared to their male counterparts in the same sports.[9-11] Those with a prior history of migraine and those with post-traumatic migraines are slower to recover.[9,12] In collegiate football players, a statistically significant association exists between history of multiple concussions and a longer recovery time.[13] High school athletes took longer to recover from neurocognitive deficits than collegiate athletes following a concussion.[14]

THE ROLE OF PHYSICAL THERAPY

Those who have protracted recovery can experience symptoms, impairments and functional losses that can be managed by Physical Therapists. These include headaches, dizziness, neck pain, fatigue, balance disturbances, oculomotor changes, and decreased coordination.[15,16] Physical Therapists are part of the multidisciplinary team that has the ability to manage patients with vestibular rehabilitation, spine rehabilitation and controlled activity progression.[15-20]

Vestibular-Ocular Rehabilitation

The forces that cause a concussion can disrupt the neurons that run along the vestibulospinal tracts, control the vestibular-ocular reflex, and link central vestibular pathways.[21,22] The peripheral vestibular receptors can also be injured during a concussion.[21,23] Physical Therapists can provide treatment for balance dysfunctions, gaze stabilization activities, vestibular habituation activities, and canalith repositioning.[24-26] In the same way, oculomotor control can be compromised through axonal injury or blunt trauma to the visual control systems.[27-32] Physical Therapists can provide treatments that are directed towards addressing impairments in ocular motor control such as convergence,[33-37] smooth pursuits,[38-43] saccades,[41-45] and ocular fixation.[42-44]

Cervical Rehabilitation

Dysfunctions of the neck, particularly the upper cervical spine, can be responsible for producing neck pain and headaches,[46-50] dizziness,[51-53] oculomotor disturbances,[39,54-56] and postural dysfunctions.[53,57-59] There are multiple isolated impairments that can potentially exist in the cervical spine following a concussion. Each of these impairments can be responsible for producing one or more of the symptoms noted above.

Physical Therapists can refine their cervical-based care into three broader components of treatment that address:

- Cervical mobility dysfunctions
- Neuromuscular control
- Strengthening

Cervical Mobility Dysfunctions

The first component to address is cervical mobility, which can be influenced by intra and extra articular factors. Although all segments of the cervical spine should be considered, the mobility of C1/C2 should be of particular importance. This area of the upper cervical spine can produce pain, loss of rotational mobility, headaches, and alter postural control.[46,51,52,60] Manual Therapy has been shown to have positive benefits for treatment of hypomobile segments in the cervical and thoracic spine for individuals following a concussion and whiplash associated disorders.[50,51,61,62] Since the thoracic spine can influence the cervical spine, it should also be considered with evaluation and treatment of the cervical spine.[63]

Neuromuscular Control

The rapid acceleration/deceleration of the head can result in trauma to the mechanoreceptors in the cervical spine. The deep cervical flexor muscles are richly innervated with muscle spindles that provide proprioceptive and kinesthetic feedback.[64] Altered proprioceptive input in the neck can result in altered perceived head position.[65] Higher rates of joint position error are noted in subjects with chronic whiplash-associated disorder compared to controls without cervical injury.[66] This is consistent with altered proprioceptive function observed after injuries in other areas of the body.[67]

Treatment for neuromuscular control needs to include activities that involve the ability to coordinate muscle contraction in order to maintain a cervical posture. Cranio cervical flexion (CCF) with pressure biofeedback is a low load exercise approach that helps refine the individual's ability to grade muscle activity of the deep neck flexors (longus capitus and longus colli), while inhibiting the sternocleidomastoid and anterior scalene muscles. A randomized controlled trial by Jull, found this training technique helpful in treating cervicogenic headaches.[68]

Joint reposition sense is another component for normal cervical function.[39,69,70] A head mounted laser and a target can be used to track relocation accuracy after active horizontal head movements. In individuals with chronic neck pain, improvements in cervical kinesthesia (head reposition accuracy) was associated with decreased neck pain, improved cervical range of motion, and improved self-reported functional improvement.[70]

Good postural alignment helps improve muscular function by maximizing length tension relationships.[71] Suboccipital and anterior chest wall tightness should be addressed with stretching to help facilitate improved cervical spine posture.[46,60,72] Addressing body mechanics and posture during school, activities of daily living and work can reduce strain on the spine that can lead to headaches and neck pain.[73-75]

Strengthening

The final component of overall cervical treatment is strengthening the cervical and periscapular muscles. The Deep Neck Flexor Endurance (DNFE) Test is a way to measure the strength of the neck stabilizers. Hold time durations for the DNFE test were statistically and clinically significantly different between individuals without and with neck pain. Mean time for those without neck pain was 39 seconds.[76] Normative times for asymptomatic men and women have be documented (Men = 39 seconds, Women = 29 seconds).[77] It is reasonable to use these outcomes as goals for muscle strength during the late phase of deficit management or early return to sports phase of recovery.

Smaller mean neck circumference, smaller mean neck to head ratio and weaker mean overall neck strength were significantly associated with concussion. Collins reported for each one pound increase in neck strength, there was a 5% reduction in the risk of concussion.[78] A program of general muscular strengthening for the neck and periscapular muscles should be considered during late phase rehabilitation.

Exertional Activity Progression

There are three strategies for Physical Therapists to organize exertional aerobic activities:

- Light to moderate aerobic exercise
- Controlled graded aerobic exercise
- Exercise as an Adjunct to Managing Anxiety, Depression, and Sleep Disturbances

Light to Moderate Aerobic Exercise

Gagnon noted that children and adolescents who participated in light aerobic exercise had improved post-concussion outcomes compared to those who did not.[79,80] Their patients exercised at 50-60% of their predicted max heart rate (220-age). Reed also found similar improvements with light aerobic activity in youth athletes done at the same intensities.[81] In college athletes, mild to moderate activity was found to be a safe adjunct to care.[82]

Graded Aerobic Exercise

Some athletes may experience exercise intolerance following a concussion that has not resolved within 7-10 days.[83] These athletes may be experiencing dysfunctions in their autoregulatory control of heart

rate responses attributed to imbalances in sympathetic/parasympathetic activity.[83-88] Leddy initially proposed a system of subsymptom threshold exercise that was based on the Balke Protocol. Exercise for individuals with post-concussion syndrome was prescribed at 80% of the heart rate at which concussion symptoms were provoked during exercise testing.[89] Interrater reliability for performing the Balke protocol was found to be high in a follow up study.[90] Leddy refined the testing procedures by modifying the protocol treadmill speed, and incorporating thresholds for changes in symptoms and rate of perceived exertion (RPE). This new protocol is known as the Buffalo Concussion Treadmill Test and is recommended for patients with noted exercise or autonomic sensitivity.[91]

Exercise as an Adjunct to Managing Anxiety, Depression, and Sleep Disturbances

Following a concussion an athlete is at risk of secondary conditions such as anxiety, depression, and sleep disturbances. A Cochrane Review on exercise and depression for adults 18 years and older, reported a small effect over control interventions in reducing depression symptoms. It was also shown to be no more effective than standard psychological or pharmacological treatments.[92] The Cochrane Review reported that exercise was a good adjunct to treating depression due to its associated benefits and having very few associated negative side effects.

Another Cochrane Review examined the effect of exercise on treating anxiety and depression in children, adolescents and young adults no older than 20 years old. Again, a small effect was noted in the ability of exercise to lessen anxiety and depression in this population.[93] This benefit was maintained regardless of whether the exercise was performed at low or high intensity levels. Exercise therapy has a place in mitigating the effect of depression due to withdrawal from normal daily activities, and as an adjunct to typical medical care in those patients that are experiencing clinical anxiety and depression.[16]

Sleep can often be disrupted in the post-concussion populations. The Clinical Practice Guidelines for Concussion/Mild Traumatic Brain Injury and Persistent Symptoms recommends considering exercise as part of sleep management.[16]

Addressing Challenges Facing Physical Therapists

A concussion is a functional disturbance to the brain without observable structural injury.[94] The lack of a pathoanatomical model, the multitude of non-specific symptoms, and the potential for confounding influence from co-morbidities is a challenge for Physical Therapists in developing appropriate treatment plans.

Conceptual models can be used to organize physical and abstract information. This can assist the clinician to synthesize complex clinical information into meaningful groups or patterns.[95] Well-developed models can allow the user to visualize complex relationships into simple and discrete visual forms.[95] The initial concepts for a conceptual model for the Physical Therapy management of protracted recovery were proposed by the author.[96] These concepts were refined and expanded as part of this commentary.

Purpose

The purpose of this clinical commentary is to describe a new conceptual model that provides a framework for Physical Therapy management of patients with protracted recovery following a sports-related concussion.

CONCEPTUAL MODEL

This conceptual model is for post-concussion patients that do not recover spontaneously within 7-10 days. This model is made up of four levels of treatment considerations. The levels of treatment consideration are: Recovery Time Line, Phases of Recovery, Progression of Treatment, and Physical Therapy Treatment Domains. (Figure 1)

Recovery Time Line

The Recovery Time Line is on the bottom of the model. It starts with the onset of the concussion and moves right with the passage of time. The time line ends with unrestricted return to sports. The time line does not provide any discrete time intervals, since the recovery time from a concussion can be variable.

Phases of Recovery

The next level of treatment above the Recovery Time Line is Phases of Recovery. There are three phases that run from left to right. The first phase is termed

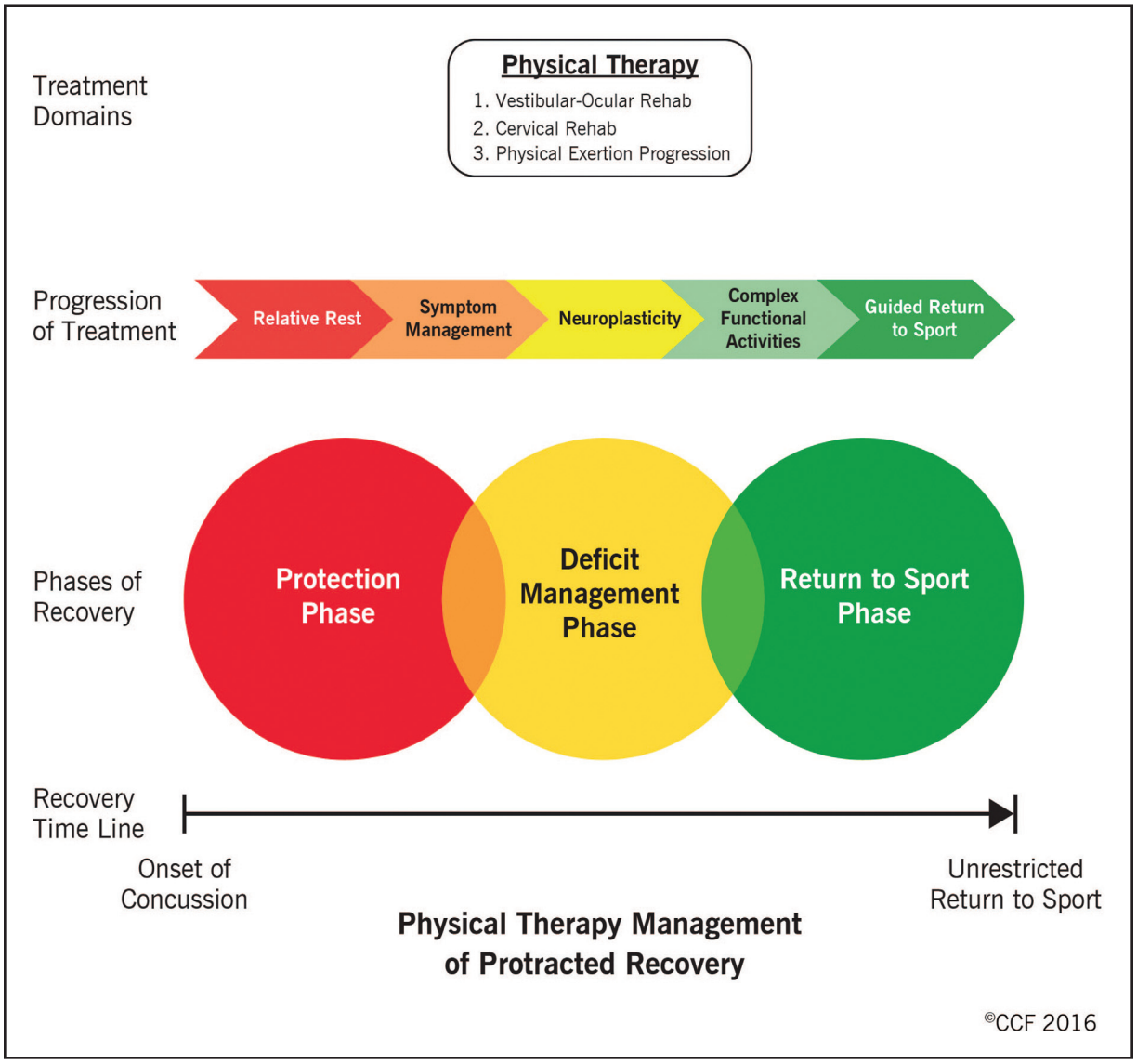

Figure 1.

the Protection Phase. It is represented by a red circle. The color strengthens the concept of protection and stresses preventing additional trauma and avoiding overtasking the neurometabolic recovery process.[2,3,97-99] It does not represent absolute rest.[100-104] The second phase is represented by a yellow circle and is named the Deficit Management Phase. This phase is focused on addressing impairments, neuroplasticity, and normalizing full function. The last phase in this model is the Return to Sport Phase and is represented by a green circle. This phase represents progressive return to safe sporting activities. The Return to Sports Phase ends when the athlete safely returns to full and unrestricted sports participation. There is overlapping between the Deficit Management Phase and the two other phases, since there is no clear indication when one phase ends and the next starts.

Progression of Treatment

The third level of treatment consideration is termed Progression of Treatment. As time passes from the initial injury, there needs to be an evolving focus on the goals of treatment and the types of treatment activities emphasized. There are five treatment progressions that move from left to right, also using the red, yellow, green color coding.

Relative Rest is the initial treatment focus in the progression of care. Relative Rest is controlled

activity and "rest as needed". Symptoms are closely monitored and patient clinical status is assessed to determine appropriate activities.[101,105,106] The patient is educated regarding which activities should be avoided and which activities should be modified.[107]

Symptom Management is the second treatment focus in the progression of care. There is a proactive shift towards managing potential symptom triggers.[80-82,86,100-102,108] These triggers may arise from an underlying autonomic dysfunction from the concussion or developing deconditioning from reduced activity levels.[83,86,109] Triggers can also exist from impairments to the cervical spine or vestibular system.[20,110] Physical Therapy should focus on progressing activity level and function by mitigating existing barriers.[6]

Neuoplasticity is the third treatment focus in the progression of care. Treatment activities incorporated should stimulate neurological plasticity in order to maximize long term neurological recovery.[98,99,111-114] Multi-sensory activities in situations that are purposeful and meaningful result in neuroplasticity.[111,113,115]

Complex Functional Activities is the fourth treatment focus in the progression of care. Treatment should emphasize maximizing full functional recovery.[15,115] Full functional recovery rehabilitation would involve real-life functional movements, occurring in a variety of sensory environments, and incorporating dual task activities that would approximate normal daily function for the individual.[116,117]

Guided Return to Sports is the last treatment progression of care. Sports-specific activities that are determined to be safe are emphasized. Each sport and position has a different relative risk to the athlete that must be considered when selecting appropriate activities.[118-120] The individual's prior history of concussions and baseline function must also be considered before the patient is released back to their sport without restrictions.[5,121-123]

Physical Therapy Domains:

The Physical Therapy Domains are situated at the top of the conceptual model. They are the areas of Physical Therapist practice through which the clinician can directly impact the care of an athlete following a concussion. Previous discussion in this commentary supports their place within this model. Specific treatment activities selected for any domain are dependent on the residual deficits and the point of recovery on the time line.

There are three domains in which Physical Therapist can impact the residual deficits that remain during protracted recovery:

1. Vestibular-Ocular Rehab
2. Cervical Spine Rehab
3. Exertion Activity Progression

A Physical Therapist may encounter patients with multiple deficits that require multiple domains of care.[124] If one type of treatment domain is outside the therapist's knowledge base, they should consider collaborating with another therapist that is able to address the specific deficit that cannot be appropriately managed by a single therapist.

CONCLUSION

This conceptual model was developed from a thorough review of the literature to specifically describe the full scope of care that Physical Therapy can provide to patients recovering from a sports-related concussion. The conceptual model is made up of four levels of treatment consideration oriented vertically. Each level is dependent on the level of treatment consideration below it. The model progresses vertically, the levels become more specific to the role of Physical Therapy in the management of the recovering athlete. Horizontally, as the time line moves away from the onset of concussion, the model provides a pathway for progressing treatment.

This model can help an individual therapist organize their treatment plan, and improve their understanding of when they may need to collaborate. In addition, this model can be used by physicians and other healthcare professionals to recognize which deficits are best managed by Physical Therapy in order to make appropriate referrals. The end product of this commentary is a visual representation of Physical Therapy management of protracted recovery following a sports related concussion.

REFERENCES

1. McCrory P, Meeuwisse WH, Aubry M, et al. Consensus statement on concussion in sport: The

4th international conference on concussion in sport held in zurich, november 2012. *Br J Sports Med*. 2013;47(5):250-258.

2. Giza CC, Hovda DA. The neurometabolic cascade of concussion. *J Athl Train*. 2001;36(3):228-235.
3. Giza CC, Hovda DA. The new neurometabolic cascade of concussion. *Neurosurgery*. 2014;75 Suppl 4:S24-33.
4. Rutland-Brown W, Langlois JA, Thomas KE, Xi YL. Incidence of traumatic brain injury in the united states, 2003. *J Head Trauma Rehabil*. 2006;21(6):544-548.
5. Iverson GL, Brooks BL, Collins MW, Lovell MR. Tracking neuropsychological recovery following concussion in sport. *Brain Inj*. 2006;20(3):245-252.
6. Collins MW, Kontos AP, Reynolds E, Murawski CD, Fu FH. A comprehensive, targeted approach to the clinical care of athletes following sport-related concussion. *Knee Surg Sports Traumatol Arthrosc*. 2014;22(2):235-246.
7. Masson F, Maurette P, Salmi LR, et al. Prevalence of impairments 5 years after a head injury, and their relationship with disabilities and outcome. *Brain Inj*. 1996;10(7):487-497.
8. McCrea M, Guskiewicz K, Randolph C, et al. Incidence, clinical course, and predictors of prolonged recovery time following sport-related concussion in high school and college athletes. *J Int Neuropsychol Soc*. 2013;19(1):22-33.
9. Scopaz KA, Hatzenbuehler JR. Risk modifiers for concussion and prolonged recovery. *Sports Health*. 2013;5(6):537-541.
10. Kostyun RO, Hafeez I. Protracted recovery from a concussion: A focus on gender and treatment interventions in an adolescent population. *Sports Health*. 2015;7(1):52-57.
11. Laker SR. Epidemiology of concussion and mild traumatic brain injury. *PM R*. 2011;3(10 Suppl 2):S354-8.
12. Mihalik JP, Stump JE, Collins MW, Lovell MR, Field M, Maroon JC. Posttraumatic migraine characteristics in athletes following sports-related concussion. *J Neurosurg*. 2005;102(5):850-855.
13. Guskiewicz KM, Weaver NL, Padua DA, Garrett WE,Jr. Epidemiology of concussion in collegiate and high school football players. *Am J Sports Med*. 2000;28(5):643-650.
14. Field M, Collins MW, Lovell MR, Maroon J. Does age play a role in recovery from sports-related concussion? A comparison of high school and collegiate athletes. *J Pediatr*. 2003;142(5):546-553.
15. Marshall S, Bayley M, McCullagh S, Velikonja D, Berrigan L. Clinical practice guidelines for mild traumatic brain injury and persistent symptoms. *Can Fam Physician*. 2012;58(3):257-67, e128-40.
16. Marshall S, Bayley M, McCullagh S, et al. Updated clinical practice guidelines for concussion/mild traumatic brain injury and persistent symptoms. *Brain Inj*. 2015;29(6):688-700.
17. THE PHYSICAL THERAPIST'S ROLE IN MANAGEMENT OF THE PERSON WITH CONCUSSION HOD P06-12-12-10 [amended HOD P06-11-15-18] [position]. http://www.apta.org/uploadedFiles/APTAorg/About_Us/Policies/Practice/ManagementConcussion.pdf. Updated 2012. Accessed April 3, 2016.
18. Physical therapist's guide to concussion. http://www.moveforwardpt.com/SymptomsConditionsDetail.aspx?cid=4f2ebb00-f1c0-4691-b2ab-742df8dffb99. Updated 2015. Accessed April 3, 2016.
19. Stewart GW, McQueen-Borden E, Bell RA, Barr T, Juengling J. Comprehensive assessment and management of athletes with sport concussion. *Int J Sports Phys Ther*. 2012;7(4):433-447.
20. Leddy JJ, Sandhu H, Sodhi V, Baker JG, Willer B. Rehabilitation of concussion and post-concussion syndrome. *Sports Health*. 2012;4(2):147-154.
21. Fife TD, Giza C. Posttraumatic vertigo and dizziness. *Semin Neurol*. 2013;33(3):238-243.
22. Nashner LM, Peters JF. Dynamic posturography in the diagnosis and management of dizziness and balance disorders. *Neurol Clin*. 1990;8(2):331-349.
23. Ouchterlony D, Masanic C, Michalak A, Topolovec-Vranic J, Rutka JA. Treating benign paroxysmal positional vertigo in the patient with traumatic brain injury: Effectiveness of the canalith repositioning procedure. *J Neurosci Nurs*. 2016;48(2):90-99.
24. Herdman S. *Vestibular rehabilitation.* 3rd ed. Philadelphia , PA: F.A. Davis Company; 2000.
25. Alsalaheen BA, Mucha A, Morris LO, et al. Vestibular rehabilitation for dizziness and balance disorders after concussion. *J Neurol Phys Ther*. 2010;34(2):87-93.
26. Alsalaheen BA, Whitney SL, Mucha A, Morris LO, Furman JM, Sparto PJ. Exercise prescription patterns in patients treated with vestibular rehabilitation after concussion. *Physiother Res Int*. 2013;18(2):100-108.
27. Leigh R, Zee D. *The neurology of eye movements.* 4th ed. New York, NY: Oxford University Press; 2006.

28. Suter P, Harvey L, eds. *Vision rehabilitation multidisciplinary care of the patient following brain injury.* New York, NY: CRC Press; 2011.
29. Brosseau-Lachaine O, Gagnon I, Forget R, Faubert J. Mild traumatic brain injury induces prolonged visual processing deficits in children. *Brain Inj*. 2008;22(9):657-668.
30. Mucha A, Collins MW, Elbin RJ, et al. A brief vestibular/ocular motor screening (VOMS) assessment to evaluate concussions: Preliminary findings. *Am J Sports Med*. 2014;42(10):2479-2486.
31. Heitger MH, Jones RD, Anderson TJ. A new approach to predicting postconcussion syndrome after mild traumatic brain injury based upon eye movement function. *Conf Proc IEEE Eng Med Biol Soc*. 2008;2008:3570-3573.
32. Fukushima J, Hatta T, Fukushima K. Development of voluntary control of saccadic eye movements. I. age-related changes in normal children. *Brain Dev*. 2000;22(3):173-180.
33. Scheiman M, Gwiazda J, Li T. Non-surgical interventions for convergence insufficiency. *Cochrane Database Syst Rev*. 2011;(3):CD006768. doi(3):CD006768.
34. Scheiman M, Mitchell GL, Cotter S, et al. A randomized clinical trial of treatments for convergence insufficiency in children. *Arch Ophthalmol*. 2005;123(1):14-24.
35. Scheiman M, Cooper J, Mitchell GL, et al. A survey of treatment modalities for convergence insufficiency. *Optom Vis Sci*. 2002;79(3):151-157.
36. Scheiman M, Gallaway M, Frantz KA, et al. Nearpoint of convergence: Test procedure, target selection, and normative data. *Optom Vis Sci*. 2003;80(3):214-225.
37. Thiagarajan P, Ciuffreda KJ. Effect of oculomotor rehabilitation on vergence responsivity in mild traumatic brain injury. *J Rehabil Res Dev*. 2013;50(9):1223-1240.
38. Kongsted A, Jorgensen LV, Bendix T, Korsholm L, Leboeuf-Yde C. Are smooth pursuit eye movements altered in chronic whiplash-associated disorders? A cross-sectional study. *Clin Rehabil*. 2007;21(11):1038-1049.
39. Heikkila HV, Wenngren BI. Cervicocephalic kinesthetic sensibility, active range of cervical motion, and oculomotor function in patients with whiplash injury. *Arch Phys Med Rehabil*. 1998;79(9):1089-1094.
40. Sharpe JA. Neurophysiology and neuroanatomy of smooth pursuit: Lesion studies. *Brain Cogn*. 2008;68(3):241-254.
41. Heitger MH, Jones RD, Macleod AD, Snell DL, Frampton CM, Anderson TJ. Impaired eye movements in post-concussion syndrome indicate suboptimal brain function beyond the influence of depression, malingering or intellectual ability. *Brain*. 2009;132(Pt 10):2850-2870.
42. Ciuffreda KJ, Kapoor N, Rutner D, Suchoff IB, Han ME, Craig S. Occurrence of oculomotor dysfunctions in acquired brain injury: A retrospective analysis. *Optometry*. 2007;78(4):155-161.
43. Kapoor N, Ciuffreda KJ. Vision disturbances following traumatic brain injury. *Curr Treat Options Neurol*. 2002;4(4):271-280.
44. Eden GF, Stein JF, Wood HM, Wood FB. Differences in eye movements and reading problems in dyslexic and normal children. *Vision Res*. 1994;34(10):1345-1358.
45. Biscaldi M, Fischer B, Aiple F. Saccadic eye movements of dyslexic and normal reading children. *Perception*. 1994;23(1):45-64.
46. Treleaven J, Jull G, Atkinson L. Cervical musculoskeletal dysfunction in post-concussional headache. *Cephalalgia*. 1994;14(4):273-9; discussion 257.
47. Zasler ND. Sports concussion headache. *Brain Inj*. 2015;29(2):207-220.
48. Jull G, Barrett C, Magee R, Ho P. Further clinical clarification of the muscle dysfunction in cervical headache. *Cephalalgia*. 1999;19(3):179-185.
49. Jull G. Management of cervical headache. *Man Ther*. 1997;2(4):182-190.
50. Racicki S, Gerwin S, Diclaudio S, Reinmann S, Donaldson M. Conservative physical therapy management for the treatment of cervicogenic headache: A systematic review. *J Man Manip Ther*. 2013;21(2):113-124.
51. Wrisley DM, Sparto PJ, Whitney SL, Furman JM. Cervicogenic dizziness: A review of diagnosis and treatment. *J Orthop Sports Phys Ther*. 2000;30(12):755-766.
52. Malmstrom EM, Karlberg M, Melander A, Magnusson M, Moritz U. Cervicogenic dizziness - musculoskeletal findings before and after treatment and long-term outcome. *Disabil Rehabil*. 2007;29(15):1193-1205.
53. Kristjansson E, Treleaven J. Sensorimotor function and dizziness in neck pain: Implications for assessment and management. *J Orthop Sports Phys Ther*. 2009;39(5):364-377.
54. Storaci R, Manelli A, Schiavone N, Mangia L, Prigione G, Sangiorgi S. Whiplash injury and oculomotor dysfunctions: Clinical-posturographic correlations. *Eur Spine J*. 2006;15(12):1811-1816.

55. Treleaven J, Jull G, LowChoy N. Smooth pursuit neck torsion test in whiplash-associated disorders: Relationship to self-reports of neck pain and disability, dizziness and anxiety. *J Rehabil Med*. 2005;37(4):219-223.
56. Tjell C, Rosenhall U. Smooth pursuit neck torsion test: A specific test for cervical dizziness. *Am J Otol*. 1998;19(1):76-81.
57. Rubin AM, Woolley SM, Dailey VM, Goebel JA. Postural stability following mild head or whiplash injuries. *Am J Otol*. 1995;16(2):216-221.
58. Karnath HO, Reich E, Rorden C, Fetter M, Driver J. The perception of body orientation after neck-proprioceptive stimulation. effects of time and of visual cueing. *Exp Brain Res*. 2002;143(3):350-358.
59. Yu LJ, Stokell R, Treleaven J. The effect of neck torsion on postural stability in subjects with persistent whiplash. *Man Ther*. 2011;16(4):339-343.
60. Page P. Cervicogenic headaches: An evidence-led approach to clinical management. *Int J Sports Phys Ther*. 2011;6(3):254-266.
61. Schneider KJ, Meeuwisse WH, Nettel-Aguirre A, et al. Cervicovestibular rehabilitation in sport-related concussion: A randomised controlled trial. *Br J Sports Med*. 2014;48(17):1294-1298.
62. Reid SA, Rivett DA, Katekar MG, Callister R. Comparison of mulligan sustained natural apophyseal glides and maitland mobilizations for treatment of cervicogenic dizziness: A randomized controlled trial. *Phys Ther*. 2014;94(4):466-476.
63. Krauss J, Creighton D, Ely JD, Podlewska-Ely J. The immediate effects of upper thoracic translatoric spinal manipulation on cervical pain and range of motion: A randomized clinical trial. *J Man Manip Ther*. 2008;16(2):93-99.
64. Boyd-Clark LC, Briggs CA, Galea MP. Muscle spindle distribution, morphology, and density in longus colli and multifidus muscles of the cervical spine. *Spine (Phila Pa 1976)*. 2002;27(7):694-701.
65. Taylor JL, McCloskey DI. Illusions of head and visual target displacement induced by vibration of neck muscles. *Brain*. 1991;114 (Pt 2)(Pt 2):755-759.
66. Treleaven J, Jull G, Sterling M. Dizziness and unsteadiness following whiplash injury: Characteristic features and relationship with cervical joint position error. *J Rehabil Med*. 2003;35(1):36-43.
67. Garn SN, Newton RA. Kinesthetic awareness in subjects with multiple ankle sprains. *Phys Ther*. 1988;68(11):1667-1671.
68. Jull G, Trott P, Potter H, et al. A randomized controlled trial of exercise and manipulative therapy for cervicogenic headache. *Spine (Phila Pa 1976)*. 2002;27(17):1835-43; discussion 1843.
69. Loudon JK, Ruhl M, Field E. Ability to reproduce head position after whiplash injury. *Spine (Phila Pa 1976)*. 1997;22(8):865-868.
70. Revel M, Minguet M, Gregoy P, Vaillant J, Manuel JL. Changes in cervicocephalic kinesthesia after a proprioceptive rehabilitation program in patients with neck pain: A randomized controlled study. *Arch Phys Med Rehabil*. 1994;75(8):895-899.
71. Hagio S, Kouzaki M. The flexible recruitment of muscle synergies depends on the required force-generating capability. *J Neurophysiol*. 2014;112(2):316-327.
72. Zito G, Jull G, Story I. Clinical tests of musculoskeletal dysfunction in the diagnosis of cervicogenic headache. *Man Ther*. 2006;11(2):118-129.
73. Kim EK, Kim JS. Correlation between rounded shoulder posture, neck disability indices, and degree of forward head posture. *J Phys Ther Sci*. 2016;28(10):2929-2932.
74. Filho NM, Azevedo E Silva G, Coutinho ES, Mendonca R, Santos V. Association between home posture habits and neck pain in high school adolescents. *J Back Musculoskelet Rehabil*. 2016.
75. Alvarez-Melcon AC, Valero-Alcaide R, Atin-Arratibel MA, Melcon-Alvarez A, Beneit-Montesinos JV. Effects of physical therapy and relaxation techniques on the parameters of pain in university students with tension-type headache: A randomised controlled clinical trial. *Neurologia*. 2016.
76. Harris KD, Heer DM, Roy TC, Santos DM, Whitman JM, Wainner RS. Reliability of a measurement of neck flexor muscle endurance. *Phys Ther*. 2005;85(12):1349-1355.
77. Domenech MA, Sizer PS, Dedrick GS, McGalliard MK, Brismee JM. The deep neck flexor endurance test: Normative data scores in healthy adults. *PM R*. 2011;3(2):105-110.
78. Collins CL, Fletcher EN, Fields SK, et al. Neck strength: A protective factor reducing risk for concussion in high school sports. *J Prim Prev*. 2014;35(5):309-319.
79. Gagnon I, Grilli L, Friedman D, Iverson GL. A pilot study of active rehabilitation for adolescents who are slow to recover from sport-related concussion. *Scand J Med Sci Sports*. 2015.
80. Gagnon I, Galli C, Friedman D, Grilli L, Iverson GL. Active rehabilitation for children who are slow to recover following sport-related concussion. *Brain Inj*. 2009;23(12):956-964.
81. Reed N, Greenspoon D, Iverson GL, et al. Management of persistent postconcussion

symptoms in youth: A randomised control trial protocol. *BMJ Open*. 2015;5(7):e008468-2015-008468.

82. Maerlender A, Rieman W, Lichtenstein J, Condiracci C. Programmed physical exertion in recovery from sports-related concussion: A randomized pilot study. *Dev Neuropsychol*. 2015;40(5):273-278.
83. Kozlowski KF, Graham J, Leddy JJ, Devinney-Boymel L, Willer BS. Exercise intolerance in individuals with postconcussion syndrome. *J Athl Train*. 2013;48(5):627-635.
84. King ML, Lichtman SW, Seliger G, Ehert FA, Steinberg JS. Heart-rate variability in chronic traumatic brain injury. *Brain Inj*. 1997;11(6):445-453.
85. Carter JB, Banister EW, Blaber AP. Effect of endurance exercise on autonomic control of heart rate. *Sports Med*. 2003;33(1):33-46.
86. Leddy JJ, Kozlowski K, Fung M, Pendergast DR, Willer B. Regulatory and autoregulatory physiological dysfunction as a primary characteristic of post concussion syndrome: Implications for treatment. *NeuroRehabilitation*. 2007;22(3):199-205.
87. Gall B, Parkhouse WS, Goodman D. Exercise following a sport induced concussion. *Br J Sports Med*. 2004;38(6):773-777.
88. Abaji JP, Curnier D, Moore RD, Ellemberg D. Persisting effects of concussion on heart rate variability during physical exertion. *J Neurotrauma*. 2016;33(9):811-817.
89. Leddy JJ, Kozlowski K, Donnelly JP, Pendergast DR, Epstein LH, Willer B. A preliminary study of subsymptom threshold exercise training for refractory post-concussion syndrome. *Clin J Sport Med*. 2010;20(1):21-27.
90. Leddy JJ, Baker JG, Kozlowski K, Bisson L, Willer B. Reliability of a graded exercise test for assessing recovery from concussion. *Clin J Sport Med*. 2011;21(2):89-94.
91. Leddy JJ, Willer B. Use of graded exercise testing in concussion and return-to-activity management. *Curr Sports Med Rep*. 2013;12(6):370-376.
92. Rimer J, Dwan K, Lawlor DA, et al. Exercise for depression. *Cochrane Database Syst Rev*. 2012;7:CD004366.
93. Larun L, Nordheim LV, Ekeland E, Hagen KB, Heian F. Exercise in prevention and treatment of anxiety and depression among children and young people. *Cochrane Database Syst Rev*. 2006;(3)(3):CD004691.
94. McCrory P, Meeuwisse W, Johnston K, et al. Consensus statement on concussion in sport - the third international conference on concussion in sport held in zurich, november 2008. *Phys Sportsmed*. 2009;37(2):141-159.
95. Earp JA, Ennett ST. Conceptual models for health education research and practice. *Health Educ Res*. 1991;6(2):163-171.
96. Lundblad M. Development of a Conceptual model to classify physical therapy treatment for individuals with protracted recovery following a sports-related concussion. *Poster presented at: 2015 OPTA Scientific Symposium*. October 9, 2015.
97. McCrory P. Does second impact syndrome exist? *Clin J Sport Med*. 2001;11(3):144-149.
98. Griesbach GS, Gomez-Pinilla F, Hovda DA. The upregulation of plasticity-related proteins following TBI is disrupted with acute voluntary exercise. *Brain Res*. 2004;1016(2):154-162.
99. Piao CS, Stoica BA, Wu J, et al. Late exercise reduces neuroinflammation and cognitive dysfunction after traumatic brain injury. *Neurobiol Dis*. 2013;54:252-263.
100. DiFazio M, Silverberg ND, Kirkwood MW, Bernier R, Iverson GL. Prolonged activity restriction after concussion: Are we worsening outcomes? *Clin Pediatr (Phila)*. 2015.
101. Craton N, Leslie O. Is rest the best intervention for concussion? lessons learned from the whiplash model. *Curr Sports Med Rep*. 2014;13(4):201-204.
102. Silverberg ND, Iverson GL. Is rest after concussion "the best medicine?": Recommendations for activity resumption following concussion in athletes, civilians, and military service members. *J Head Trauma Rehabil*. 2013;28(4):250-259.
103. Thomas DG, Apps JN, Hoffmann RG, McCrea M, Hammeke T. Benefits of strict rest after acute concussion: A randomized controlled trial. *Pediatrics*. 2015;135(2):213-223.
104. Smorawinski J, Nazar K, Kaciuba-Uscilko H, et al. Effects of 3-day bed rest on physiological responses to graded exercise in athletes and sedentary men. *J Appl Physiol (1985)*. 2001;91(1):249-257.
105. Kutcher JS, Giza CC. Sports concussion diagnosis and management. *Continuum (Minneap Minn)*. 2014;20(6 Sports Neurology):1552-1569.
106. Schneider KJ, Iverson GL, Emery CA, McCrory P, Herring SA, Meeuwisse WH. The effects of rest and treatment following sport-related concussion: A systematic review of the literature. *Br J Sports Med*. 2013;47(5):304-307.
107. Kirelik SB, McAvoy K. Acute concussion management with remove-reduce/educate/adjust-accommodate/pace (REAP). *J Emerg Med*. 2016;50(2):320-324.

108. Ding YH, Luan XD, Li J, et al. Exercise-induced overexpression of angiogenic factors and reduction of ischemia/reperfusion injury in stroke. *Curr Neurovasc Res*. 2004;1(5):411-420.

109. Leddy J, Hinds A, Sirica D, Willer B. The role of controlled exercise in concussion management. *PM R*. 2016;8(3 Suppl):S91-S100.

110. Ellis MJ, Leddy JJ, Willer B. Physiological, vestibulo-ocular and cervicogenic post-concussion disorders: An evidence-based classification system with directions for treatment. *Brain Inj*. 2015;29(2):238-248.

111. Nudo RJ. Recovery after brain injury: Mechanisms and principles. *Front Hum Neurosci*. 2013;7:887.

112. Carro E, Trejo JL, Busiguina S, Torres-Aleman I. Circulating insulin-like growth factor I mediates the protective effects of physical exercise against brain insults of different etiology and anatomy. *J Neurosci*. 2001;21(15):5678-5684.

113. Cotman CW, Berchtold NC. Exercise: A behavioral intervention to enhance brain health and plasticity. *Trends Neurosci*. 2002;25(6):295-301.

114. Griesbach GS, Hovda DA, Molteni R, Wu A, Gomez-Pinilla F. Voluntary exercise following traumatic brain injury: Brain-derived neurotrophic factor upregulation and recovery of function. *Neuroscience*. 2004;125(1):129-139.

115. Takeuchi N, Izumi S. Rehabilitation with poststroke motor recovery: A review with a focus on neural plasticity. *Stroke Res Treat*. 2013;2013:128641.

116. Howell DR, Osternig LR, Christie AD, Chou LS. Return to physical activity timing and dual-task gait stability are associated 2 months following concussion. *J Head Trauma Rehabil*. 2015.

117. Register-Mihalik JK, Littleton AC, Guskiewicz KM. Are divided attention tasks useful in the assessment and management of sport-related concussion? *Neuropsychol Rev*. 2013;23(4):300-313.

118. Baugh CM, Kiernan PT, Kroshus E, et al. Frequency of head-impact-related outcomes by position in NCAA division I collegiate football players. *J Neurotrauma*. 2015;32(5):314-326.

119. Stamm JM, Bourlas AP, Baugh CM, et al. Age of first exposure to football and later-life cognitive impairment in former NFL players. *Neurology*. 2015;84(11):1114-1120.

120. Daneshvar DH, Nowinski CJ, McKee AC, Cantu RC. The epidemiology of sport-related concussion. *Clin Sports Med*. 2011;30(1):1-17, vii.

121. Iverson GL, Schatz P. Advanced topics in neuropsychological assessment following sport-related concussion. *Brain Inj*. 2015;29(2):263-275.

122. Losoi H, Silverberg ND, Waljas M, et al. Recovery from mild traumatic brain injury in previously healthy adults. *J Neurotrauma*. 2015.

123. Fazio VC, Lovell MR, Pardini JE, Collins MW. The relation between post concussion symptoms and neurocognitive performance in concussed athletes. *NeuroRehabilitation*. 2007;22(3):207-216.

124. Reed N, Murphy J, Dick T, et al. A multi-modal approach to assessing recovery in youth athletes following concussion. *J Vis Exp*. 2014;(91):51892. doi(91):51892.